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Editorial

Special Issue on "Secondary Metabolites: Extraction, Optimization, Identification and Applications in Food, Nutraceutical, and Pharmaceutical Industries"

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There is a growing interest in utilizing natural plant extracts in the food and beverage industries. These extracts play a vital role in improving food quality and technological advancements and have potential therapeutic benefits in treating various diseases. The protective benefits of nutritionally rich diets that contain fruits, vegetables, and whole grains are not just limited to their fiber, vitamin, and mineral contents. These diets also contain a diverse range of secondary metabolites that are organic compounds produced by various organisms, including plants, microorganisms, and animals. Unlike primary metabolites, which are essential for growth and development, secondary metabolites are not directly involved in fundamental life functions. Instead, they have specialized roles such as defense mechanisms, the attraction of pollinators, and interactions with the environment. These compounds have various chemical structures and exhibit a range of biological activities, making them of significant interest in fields such as medicine, agriculture, and industry.

Secondary metabolites are distinguished for their diverse and impressive array of biochemical and pharmacological attributes, encompassing notable traits such as antioxidant, antiviral, anticancer, and anti-inflammatory activities, among others. As a consequence, these compounds have the potential to actively contribute to disease prevention and health upkeep. Furthermore, their versatile applicability extends to various domains, including the food, nutraceutical, and pharmaceutical industries, owing to their relevance in both pharmaceutical and nutraceutical spheres.

The objective of this Special Issue (SI) is to assemble the latest contributions encompassing the realms of chemistry, extraction methodologies, and analytical techniques, alongside an exploration of the associated biological activities of secondary metabolites. Additionally, this SI encompasses an investigation into the molecular basis of bioactivities exhibited by secondary metabolites, employing a spectrum of established and cutting-edge bio-analytical methodologies.

The current Special Issue of the journal *Processes*, titled "Secondary Metabolites: Extraction, Optimization, Identification and Applications in Food, Nutraceutical, and Pharmaceutical Industries" (available at: https://www.mdpi.com/journal/processes/special_issues/Secondary_Metabolites_Applications; accessed on 8 August 2023), serves as a consolidated repository for the latest contributions from prominent researchers. The content within this Special Issue encompasses a diverse range of both theoretical studies and experimental applications, with a specific emphasis on the extraction, identification, and industrial applications of secondary metabolites.

The contributions presented by the authors in this Special Issue have made substantial strides towards achieving this objective. In addition to the research articles, the Special Issue encompasses three feature papers and a comprehensive review, which span a spectrum of subjects, effectively showcasing the multifaceted nature of the field. The thematic spectrum covered in this Special Issue encompasses an array of pertinent topics, such as advanced analytical methodologies employed in the isolation, purification, and analysis of secondary

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metabolites from diverse sources, including food, food waste, and medicinal plants, among others. Furthermore, this Special Issue delves into discussions related to secondary metabolites within the context of plants, food, biological samples, and microorganisms (i.e., fungi). Encompassing the realm of biological activities and mechanisms of action, this Special Issue provides insights into the health benefits and in vitro/in vivo evaluation of these compounds. Moreover, it explores the innovative development of novel antioxidants, as well as secondary metabolite-based nutraceuticals and functional ingredients.

For instance, Quiterio-Gutiérrez et al. [1] reported the different industrial applications of the non-pathogenic *Aspergillus niger* fungus. The study dealt with the production of kojic acid by the *A. niger* M4 strain using different concentrations of yeast extract + Zinc sulfate, which in turn were shown to influence the formation, speed of biomass, synthesis, and yield of Kojic acid. The optimum conditions were from 72 h and 96 h with 0.552 g/L and 0.510 g/L of KA using 2.5 g/L of yeast extract and with a pH of 5.5. The capacity to generate kojic acid was demonstrated by the niger M4 strain, with its production being triggered by variations in nitrogen source concentrations.

Lee et al. [2] studied the anti-obesity effects of *Salicornia herbacea* extract and isorhamnetin-3-O-glucoside (IR3G). IR3G possesses antioxidant and anti-inflammatory properties. The research evaluates their impact on 3T3-L1 adipocytes and db/db obesity mice. Both the extract and IR3G exhibit lipase inhibitory effects, reducing lipid accumulation and adipogenesis in 3T3-L1 cells. In db/db mice, the extract curbs weight gain, enhances lipid profile, and reduces adipose tissue weight, suggesting potential anti-obesity benefits.

The impact of *Thymus vulgaris* essential oil on virulence factors in *Pseudomonas syringae* strains, emphasizing growth, biofilm formation, exopolysaccharide synthesis, and motility patterns was discussed by Carezzano and colleagues [3]. The essential oil's sub-inhibitory concentrations notably impede bacterial growth rate and slope, while effectively inhibiting biofilm production and exopolysaccharide synthesis. Swimming and swarming motility patterns are also significantly disrupted across all tested oil concentrations. The findings suggest the potential of *Thymus vulgaris* essential oil as a promising antipseudomonal agent, offering a sustainable solution for managing plant infections caused by *P. syringae*.

Paredes-Camacho et al. [4] focused on characterizing Sargassum spp. from the Mexican Caribbean, addressing its environmental impact and biotechnological potential. Despite beach-related issues, Sargassum holds valuable compounds. Liquid media fermentation (LMF) was explored to extract bioactives. Five Sargassum species were collected, divided into natural and washed forms, and assessed for phenolic compounds, flavonoids, and antioxidant capacity. Fermentation using *Aspergillus niger* yielded extracts with altered compound levels. Proximal analysis revealed suitable carbon–nitrogen ratios for microbial degradation. Washed Sargassum fermentation showed increased phenolic and flavonoid content, with an average 57% antioxidant capacity, supporting its viability for bioactive compound extraction through LMF.

The research of Mohammadi and his coworkers [5] explored Gyrophoric Acid (GA) from the lichen *Umbilicaria muhlenbergii* for breast cancer cytotoxicity. A purification process employing silica gel column chromatography was developed for GA isolation. Identification through FTIR, MS, and NMR confirmed GA's presence. Notable spectral signals were detected at 1400 cm^{-1} (aromatic region), 1400 cm^{-1} (CH3 groups), and 1650 cm^{-1} (carbonyl groups). GA exhibited strong cytotoxicity, reducing MCF-7 breast cancer cell viability by 98%, suggesting its potential as an effective anticancer agent.

In his study, Al-Nuri et al. [6] evaluated *Micromeria fruticosa* extracts (ethanol, n-hexane, water) using GC-MS and tested them for antioxidant, antimicrobial, and antitumor effects. The analysis revealed 27 secondary metabolites, including menthone, oleamide, pulegone, and menthol. Water extracts from leaves and flowers showed high DPPH scavenging activity (89.73% and 80.07%, respectively). Water stem extract exhibited potent antimicrobial activity, while ethanolic leaf and aqueous stem extracts were effective against *C. albicans* and *E. coli*. The aqueous extract of the flowers displayed notable cytostatic effects

on colon cells. Extract composition influenced activity, highlighting *Micromeria fruticosa*'s potential for nutraceutical and functional foods.

Iannone and coworkers [7] studied seven hop varieties and their craft beers using SPME-GC/MS to identify volatile compounds in the brewing process and flavonoid and polyphenol content and evaluated antioxidant activity using DPPH and ABTS assays. The research unveiled diverse chemical classes, including monoterpenes, sesquiterpenes, alcohols, esters, and fatty acids. Sesquiterpenes like β-caryophyllene and humulene dominated hop cones, while β-myrcene prevailed in hop extracts. Craft beers exhibited qualitative and quantitative volatile composition differences. All hop samples displayed strong scavenging potential against radicals, with IC50 values ranging from 0.027 to 0.047 mg/mL for DPPH and 0.023 to 0.134 mg/mL for ABTS. Positive correlations emerged with polyphenol and flavonoid contents.

This study of Esposito et al. [8] focused on addressing prolonged fatigue through a food supplement containing pomegranate extract, B vitamins, and vitamin C. Prolonged fatigue negatively impacts quality of life and can result from vitamin deficiency and chronic inflammation. The investigation examines the supplement's potential effectiveness in alleviating fatigue. The chemical analysis of pomegranate extract revealed the presence of ellagitannins, gallotannins, and phenolic acids. A survey involving 78 participants over one month indicated significant improvements in fatigue levels and quality of life without adverse effects. These initial findings suggest the supplement's potential to combat prolonged fatigue.

Rahman and colleagues [9] investigated the neuropharmacological potential of *Gomphandra tetrandra* (Wall.) Sleumer and its in silico interaction with β-amyloid precursor protein. The plant is traditionally used for mental disorder treatment. GC-MS analysis identified fifteen compounds, with 9-, 12-, and 15-octadecatrienoic acid (z,z,z) being prominent. The extract exhibited strong in vitro antioxidant activity and significant neurological effects in Swiss albino mice. Computer-aided analysis pinpointed 1,5-diphenyl-2h-1,2,4-triazoline-3-thione as a potential neuroactive compound with strong binding to β-amyloid precursor protein. Overall, this study suggests *G. tetrandra* extract could be a promising natural agent against neurological disorders, particularly Alzheimer's disease.

The PROMANCOA modular technology (PMT) designed by Núñez-Sellés et al. [10] is meant to valorize agricultural biowastes from mango and cocoa cultivars, aligning with the circular economy concept. The modular approach involves four stages: raw material selection and collection, processing, extraction for bioactive extracts and ingredients, and quality control. PMT's application to mango stem bark, tree branches, cocoa pod husk, and bean shells in the Dominican Republic demonstrates its potential. This technology offers avenues for generating value-added bioactive components for food, feed, nutraceutical, and cosmeceutical products. Beyond market potential, PMT also contributes to reducing greenhouse gas emissions from agricultural biowastes.

The phytochemicals from *Ficus sycomorus* and their effects on rabbits were reported on by Dawod et al. [11]. The stem bark was extracted with 70% methanol, and its composition was analyzed using UPLC-QToF-MS and 1H NMR. Identified compounds included procyanidins, genistein, luteolin, and more. In a trial with rabbits, the extract was administered at different doses for 60 days. While the extract contained potentially beneficial compounds, it negatively impacted rabbit performance indices and carcass quality. Notably, the extract showed potential anti-dyslipidemia effects by reducing LDL and triglycerides levels in rabbits.

Finally, the review of Wang et al. [12] outlined the signaling molecule types, intracellular conduction, and multi-molecular crosstalk during endophytic bacteria–medicinal plant interactions. The molecular mechanism behind signal-induced medical metabolite accumulation and regulation is explored. This study's insights can guide the synthesis of active pharmaceutical ingredients using endophytic bacteria and medicinal plants within bioreactor setups.

Conflicts of Interest: The author declares no conflict of interest.

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